Get ready for Gaia: cool white dwarfs in common proper motion with Tycho stars

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Abstract. We discuss the Gaia Data Release 1 (September 2016) and preliminary work on maximising the benefit for cool white dwarf (WD) science in advance of the full parallax catalogue which will appear around one year later in DR2. The Tycho catalogue is used in conjunction with the all–sky ground based astrometric/photometric SuperCOSMOS Sky Survey in order to identify candidate faint common proper motion objects to the Tycho stars. Gaia DR1 is supplemented by the Tycho–Gaia Astrometric Solution catalogue containing some 2 million parallaxes with Hipparcos–like precision for Tycho stars. While hotter, brighter WDs are present in Tycho, cooler examples are much rarer (if present at all) and CPM offers one method to infer precision distances for a statistically useful sample of these very faint WDs.

1. Introduction

ESA's Gaia mission has been in routine operations for two years. The first intermediate data release (GDR1) occurred in September 2016 and is based on the first 14 months of data gathered by the spacecraft. Such a time baseline is insufficient to disentangle reliably proper motion and parallax so the primary data product of GDR1 will be a map of around one billion stars to V $\sim$ 20 with mean epoch positions and single passband photometry but no proper motions nor parallaxes. However, by using the Tycho data from the precursor Hipparcos mission it is possible to anchor the positions for over 2 million brighter stars (V < 11.5) at a mean early epoch around 1991 and hence solve for proper motion and parallax. This yields trigonometric distances for 20× as many stars as in the Hipparcos catalogue with similar precision (Michalik et al. 2015). A bonus part of GDR1 are these Tycho–Gaia Astrometric Solution (TGAS) sources. Data are released to the community via a central Science Archive system and associated partner Data Centers (e.g. CDS) with extensive exploitation facilities and documentation[1].

2. White Dwarfs in Hipparcos and Tycho

There are 10 or so WDs in the Hipparcos catalogue (which is at best complete to V $\sim$ 9) with parallaxes measured at a 5σ level. The number of WDs present in the Tycho

[1] http://archives.esac.esa.int/gaia/

catalogue (90% complete to V $\sim$ 11.5) is larger of course, so TGAS will deliver in itself a major step forward for WD science via the addition of precision distances (and therefore WD masses, radii, etc). However the TGAS WDs will be biased towards the hot, bright end of the WD luminosity function simply because of the bright magnitude limit of that catalogue coupled with the extreme faintness of cooler WDs.

3. White Dwarfs in common proper motion with Tycho stars

One method for expanding significantly the sample of cool WDs with measured distances in GDR1 is to find those with high proper motion using existing ground–based catalogues, e.g. the digitised optical all–sky Schmidt photographic surveys, and associate them with Tycho stars via common proper motion. This can be done with usefully high confidence given a sufficiently high lower proper motion cut such that in any given part of the sky the likelihood of finding by chance two nearby stars with the same high proper motion is negligibly small. Figure 1 illustrates this using the SuperCOSMOS Science Archive[2] RECONS proper motion survey plus lower proper motion supplement (Hambly et al. 2004; Rowell & Hambly 2011) down to a lower proper motion limit of 80 mas/yr. Wide binary candidates with separations of up to 16.7 arcmin (1000 arcsec, corresponding to maximal separations of order 100,000 AU at 100 pc) can be identified in this way and their position in reduced proper motion / colour space shows some of them to be likely cool WDs. In Figure 2 the image and adjacent thumbnails show one example, an R = 19.7 object with R–I = 1.3 having a proper motion within 1.5σ of that of TYC 2734–750–1 (central in the main picture) which is more than 8 magnitudes brighter in R. Using common proper motion it will be possible to infer accurately the distances to a large sample of cool WDs prior to the availability of direct trigonometric parallaxes in GDR2.

4. White dwarfs in GDR2 and subsequent releases

Of course the major leap forward for the science of all WD fields of study will be from GDR2 onwards with the availability of full five–parameter astrometric solutions and (some) radial velocities (Jordan 2007). Even then full 6D kinematics will not be available for the majority of isolated cool WDs because of the unknown and generally unmeasurable radial velocity component. Moreover accurate model–independent ages are difficult to establish for such objects which leads to, for example, poor coverage in the Initial–Final Mass Relation. If, however, a cool WD can be associated with a normal star via common proper motion then the distance and radial velocity will nearly always be more accurately measured (or indeed may only be measurable) for the system using the brighter component. If the system can be identified kinematically with a cluster, association or moving group of known age and metallicity etc. then so much the better and hence the technique of 'benchmarking' systems (Gomes & Pinfield 2013; Zhao et al. 2012) identified via common proper motion will remain a valuable tool for WD science in the Gaia era.

An interesting aspect of this work is in the implementation details of the CPM search algorithm. Catalogue pairing is, of course, a solved problem in computer science

[2] `http://ssa.roe.ac.uk`

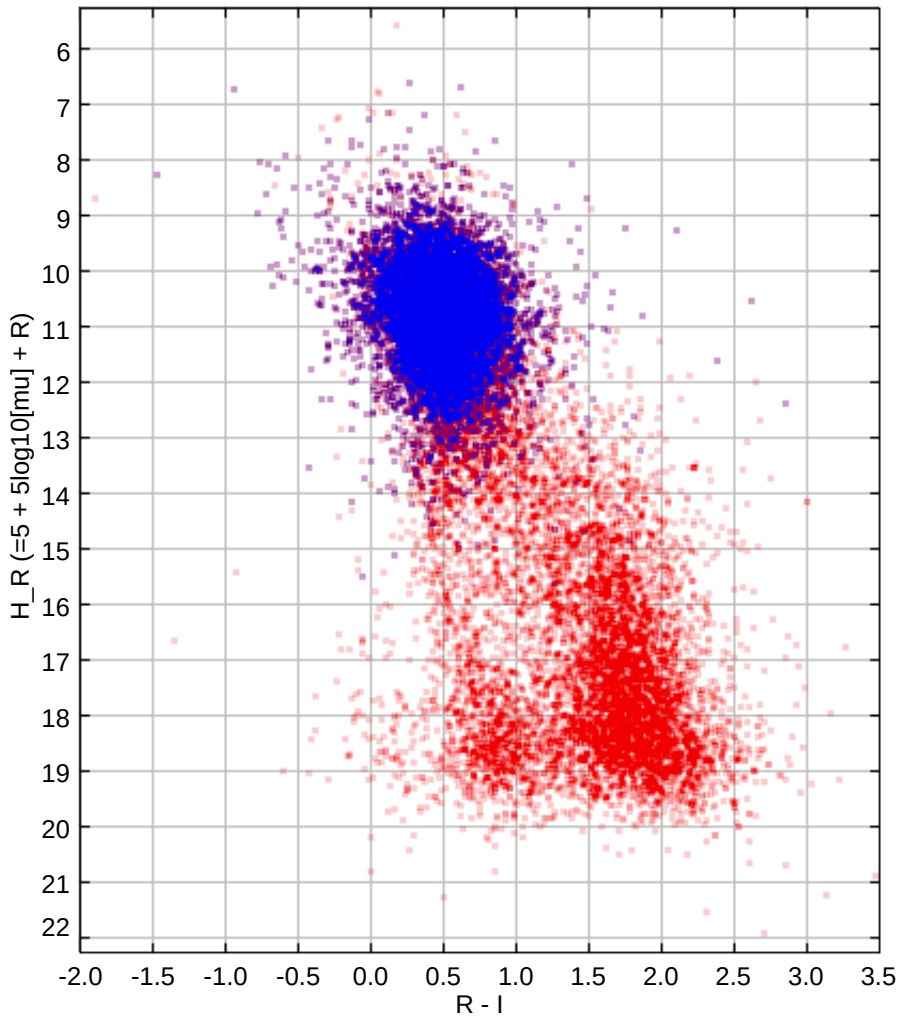

Figure 1. Reduced proper motion diagram for Tycho2 catalogue stars (blue) and 1.5σ common proper motion objects from SuperCOSMOS (red). The usual dwarf, subdwarf and WD locii trace from the upper left to the lower right in this RPM–colour space. A search radius of 1000 arcsec was used along with a lower proper motion cut of 80 mas/yr. All the red objects share common proper motion with a Tycho star.

via 'plane sweep' algorithms that deliver true $O(N \log M)$ performance (see Devereux et al. 2005 and references therein) for small search radii. For the larger search radii needed in this application, we have further refined the implementation using the 'zoned join' technique developed by Gray et al. (2004) where the input catalogue(s) are first split into separate Declination zones of extent equal to the maximum search radius required to identify CPM wide binaries (in this case 1000 arcsec). This is particularly important when scaling up to a self–join of a billion–row scale catalogue, as will be the case when GDR2 is released.

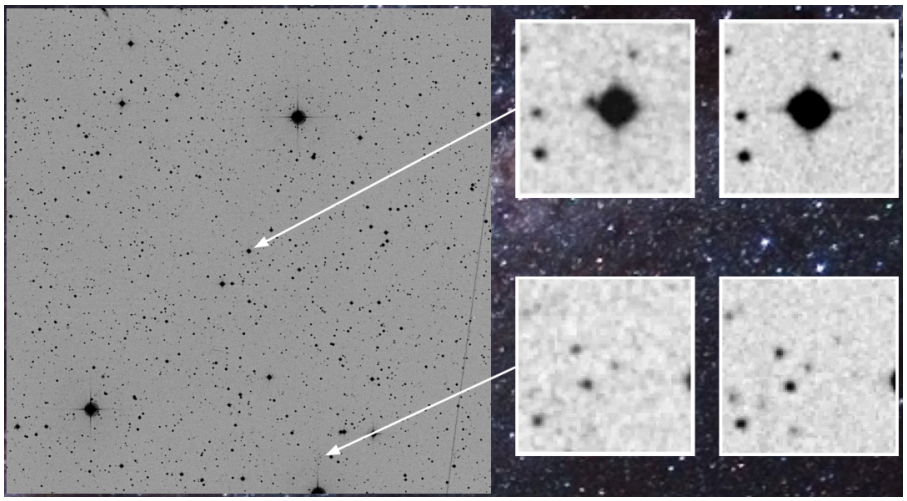

Figure 2. Example of a candidate wide binary identified via common proper motion between TYC 2734–750–1 (R = 11.3) and a cool WD (R = 19.7; R–I = 1.3). The wide angle image is 30 arcmin on each side while the thumbnails are 1 arcmin. Thumbnails on the left are from the POSS–E plate scan while those on the right are from the 2nd epoch red survey plate (exposed some 40 years later).

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